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QUIET BEARING SURFACE CHARACTERIZATION.(U)

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Surface chemical and topographical features of bearings which passed or failed Anderometer noise testing were correlated with their noise characteristics. No surface chemical differences existed between noisy or quiet bearings. The former did, however, exhibit bands of circular scratches on "polar" ends of ball surfaces with an equatorially located narrow "frost" band consisting of small (2-5 μm in diameter) pits of the type associated with contact fatigue. Quiet bearings also possessed frost bands which were

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always wider and sometimes multiple but did not possess the bands of scratches. The ability of the balls in a noisy bearing to roll freely are believed to be hindered; the resulting increase in contact-Hertz loads and sliding frictional forces result in the generation of noise. Interim solutions to the problem are also discussed.

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QUIET BEARING SURFACE CHARACTERIZATION

INTRODUCTION

In the light of increasingly sophisticated detection devices, "quiet" bearings for submarine and shipboard use have become a necessity. Current supplies of Navy quiet bearings originate from foreign vendors, and any treatments to bearing surfaces are proprietary. Navy specifications for quiet bearings stipulate only the type of steel (52100; 1.5% Cr, 1% C, Fe balance by weight), the grade, and certain dimensional tolerances. Noise levels are determined by Anderometer tests with "quiet" and "noisy" bearings differentiated by the specification limits.

A cooperative program has been undertaken by the Naval Research Laboratory (NRL) and the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) in Annapolis to determine if there were any correlation between the surface chemistry and surface topography of bearings, and their performance classification as quiet or noisy. Engineering evaluations such as metrology and Anderometer noise testing were performed by DTNSRDC personnel; NRL provided the surface evaluation using optical and scanning electron microscopy, microhardness tests, surface profilometry, energy dispersive analysis of X-rays (EDAX) and Auger spectroscopy.

A number of bearings have been evaluated, some of which have seen Fleet service. While all of the bearings herein have been subjected to an Anderometer noise test, it should be noted that not all quiet bearings are noise tested before seeing Fleet service.

Listed below are the bearings that have been examined to date. Unless otherwise stated, all have seen Fleet service.

Table 1 — Identification of noise-tested bearings

Set #	Ball Diameter (Inches)	Identification No. Quiet bearings	Noisy bearings
1	7/8	997[a]	1000[a]
2	1	208[a]	C-18[a]
3	17/32	1507[a]	1530[a]
4	1 7/16	161	
5	1 7/16	156	
6	1 7/16		F186
7	27/32	N369[b]	
8	9/16		36
9	17/32		24
10	17/32	33	
11	17/32	25	
12	17/32	C-30	
13	15/32	C-6	
14	3/4	C-24	
15	3/4	D-9	
16	19/32		C-1
17	19/32		C-2

Manuscript submitted August 3, 1981.

Table 1 (Cont'd) — Identification of noise-tested bearings

Set #	Ball Diameter (Inches)	Identification No. Quiet bearings	Noisy bearings
18	11/16		D-6
19	3/4		C-34
20	3/4		C-35
21	3/4		C-23

[a] Noise tested but no service life as such

[b] Not noise tested - new bearing

Sets 1-3 were the topic of the first progress report (1), with sets 4-11 reported on in the second progress report (2). Sets 12-21 are recently supplied bearings. This report summarizes the results of our investigations of bearing sets 1-21.

EXPERIMENTAL

Optical microscopy was performed using low power stereo microscopes and higher power examinations with a Bausch and Lomb Research II metallograph.

Scanning electron microscopy was performed with an Advanced Metals Research Model 1000 operating at 20 kV and fitted with a KEVEX EDAX attachment. Samples were oriented so they were normal to the detector.

Hardness tests were performed with a Tukon Microhardness Tester using loads ranging from 5g to 1kg, and a Wilson Tukon Tester using loads from 100g to 3kg.

Surface profilometry was performed with a Taylor Hobson Talysurf 4 with an attachment capable of measuring balls up to 1 inch in diameter. Analysis of a selected race was done by the Charles Draper Laboratories, Cambridge, Massachusetts.

Auger analysis was performed in an UHV chamber equipped with a Perkin-Elmer (PHI) Model 545 Auger microprobe, a rasterable ion gun, Ti sublimators, and liquid nitrogen cooled cryopanels. Auger derivative spectra were recorded with a 3 eV modulation, as were depth profiling measurements. The latter employed a peak-height multiplexer, and an ion gun operating in an Argon atmosphere (5×10^{-5} torr) with a rastered beam of Ar^+ ions at chosen current densities ranging between 2 and 30 $\mu A/cm^2$. The electron gun was operated at 2 kV. During depth profiling, the Ti sublimators were operating, and the cryopanels maintained at liquid nitrogen temperature to prevent contamination of the ion-milled surfaces.

RESULTS

Ferrographic analysis of grease samples removed from bearing sets 1-3 revealed only benign wear (3). Wear debris from these bearings suggest that wear modes were primarily of the normal rubbing variety. Rubbing wear was more predominant for the quiet bearing than for the noisy bearings in Set #1. Grease samples contained few extraneous contaminants.

Visual examination of bearing surfaces revealed the only consistent differences between bearings that passed or failed an Anderometer test. This difference consisted of the severity of sets of circular scratches on "poles" of the ball surfaces and the width of "frost" bands located equatorially between the polar scratches. Figure 1 shows a ball from bearing F186 with the scratches clearly visible. The width of the scratch band as well as its radius varied from bearing to bearing, but always remained concentric on noisy bearings. Bearings which passed the noise test sometimes had scratches which were equally as severe, but these did not take the form of concentric circles forming the scratch pattern shown in Figure 1. Balls taken from bearings which passed noise testing exhibited frost bands also, but these bands were much wider than those of a noisy counterpart. Some balls from passed bearings possessed more than one frost band. An example of both cases is shown in Figure 2.

Microscopic examination clearly showed that the scratches on ball surfaces were caused by abrasion, and some balls possessed numerous kinematic wear marks resulting from trapped asperities (4). Examination of frost bands revealed a number of closely spaced pits (2-5 μm in diameter) of the type associated with contact fatigue (5).

The bearing races were essentially unremarkable with respect to obvious signs of wear in the ball grooves. In some cases minimal wear occurred, as seen by the fact that finishing marks were not as pronounced on the contact surfaces, and slight discoloration due perhaps to mild heat buildup during bearing operation. Some races did exhibit signs of fretting corrosion on the outer surfaces of the outer race, particularly in bearings 156, 161 (quiet) and F186 (noisy) (6). Retainers were also unremarkable, although in bearing C-24 (quiet), large flakes of metal were found in an otherwise typical grease sample and one is shown in Figure 3. EDAX analysis revealed these flakes were not 52100 steel. Several spots on this retainer appeared burnished; however, no gross failure of the retainer was evident by visual examination.

Microhardness tests on several typical balls showed no differences between those from quiet and noisy bearings. Microhardness data showed the surface appeared harder at shallower depths. There is, however, no relative difference using the heavier loads, as is seen in Figure 4. In one case, (bearing 24 (quiet)) some minor softening of the inner race was noted under the contact surface in the ball groove. Tests on other races were inconclusive.

Surface profilometry on balls showed that as a general trend, bearings passing the Anderometer noise test contain balls possessing a surface rougher than that of a failed bearing. By taking many center-line average (CLA) measurements for each bearing, average CLA values were determined. Table 2 lists average CLA values for selected bearings.

Table 2 — Average CLA values for balls

Identification Number Quiet Bearings	Identification Number Noisy Bearings	Average CLA (μ inches)
1507		0.4
24		2.4
33		3.4
C-30		3.8
C-6		1.8
D-9		2.4
	1530	0.4
	25	1.7
	36	2.9
	C-1	2.1
	C-2	2.0
	C-34	0.8
	C-35	1.6
	C-23	2.1
Average: 2.7	Average: 1.7	

Current Navy specifications require that quiet bearings possess an average surface roughness $\leq$ 1 μ inch. Comparison of data relating the magnitude of the noise and its frequency dependence with the average CLA values for a group of noisy bearings was inconclusive, i.e. noisy bearings having approximately the same noise characteristics could have vastly different surface roughness averages. The same was true for quiet bearings. The effect of contaminant abrasive size on bearing noise has not been established, but compared to reference laboratory samples abraded by various sizes of abrasives, the scratches are on the same order of magnitude as those that would be made by 400 grit abrasives. Profilometry on a typical race showed that no measurable wear had taken place (7), and that bearing topography was exceptionally good. Surface roughness of frost bands was on the order of 10-20 μ inches.

Auger analysis on selected surfaces of solvent-cleaned balls and races was performed on bearing sets 1-3. The surfaces exhibited a contaminant carbonaceous layer over an iron oxide layer less than 5 nm thick. Typical trace contaminants ($\leq$ 2 atomic %) of S, Na, Cl, and N were found on the surfaces, their concentrations varying slightly from spot to spot and sample to sample. Depth profiling by ion milling found constituents below the oxide layer to be in their expected concentrations (1.5 atomic % Cr, 3-4 atomic % C, Fe balance). Trace contaminants were negligible--less than 0.3 atomic %. No significant surface chemical differences between quiet and noisy bearings were found.

DISCUSSION

From the work completed to date, the only consistent differences found between quiet and noisy bearings, whether before or after Fleet service is the pattern of scratches found on the surface, and the width of frost bands associated with those scratches. It would appear from our data that the events leading to the formation of these circular scratches are the prerequisites for a bearing to fail an Anderometer test. These events probably commence with an abrasive particle (or particles) becoming lodged between the retainer and the ball surface, scratching the ball as it rotates. Once the ball has become damaged in this manner, its ability to rotate freely in its retainer pocket is hindered, and is restricted to one rotational axis.

The above sequence is supported by the fact that the average surface roughness for balls from quiet bearings is generally higher than that for corresponding noisy bearings. Since the motion of the ball of the quiet bearing is not held to one axis of rotation (as can be seen in Figure 2), a larger portion of the ball surface is brought into service, hence a larger portion of the surface becomes rougher. If indeed the ability of the balls to roll freely is hampered by circular scratches of the type shown in Figure 1, there is an implied increase in the contact-Hertz loads, and a corresponding restriction on the sliding frictional forces between the races and the balls. Restricted rolling motion results then in the generation of noise (8). The mathematical treatment of bearings operating under severe compressive stresses has been discussed in Hertzian theory (9).

Secondary problems may also arise from the increase in sliding frictional force confined to a specific area. Overheating at the contact surface, causing changes in microstructure, which can result in more severe surface damage, including loss of hardness and spalling. The formation of oxides on the surface may also be affected by heating, and the role of oxides on friction and wear is not fully understood.

Although the sequence of events leading to surface scratches seems to be the initiating factor in "quiet" bearings failure, race out-of-roundness or improperly fitting retainers may also contribute to hinderance of a ball to roll freely.

The use of ion implantation, which ongoing NRL research has shown to lower the coefficient of friction and increase the abrasion resistance of bearing steels (10, 11), should be investigated as a possible solution to this problem. Preliminary work on a device to improve the ion implantation of balls has already begun by R.N. Bolster of NRL who designed and built the device. Testing of the apparatus is pending.

RECOMMENDATIONS

It is recommended that:

a. DTNSRDC conduct analysis of lubricants from quiet and noisy bearings to determine the presence and characteristics of particulate contaminants, and relate them to noise levels.

b. NRL/DTNSRDC prepare a series of lubricants containing contaminants of known size, hardness, and concentration and determine the resultant effect on noise generation. NRL will perform post-service examination of the test bearings.

c. The present program be extended to include the effect of ion implantation on bearing noise levels tested under carefully controlled conditions.

d. Pending further work on this program, strict attention should be paid to the reduction of particulate contaminants in the lubricants, and to ball, race, and retainer roundness tolerances.

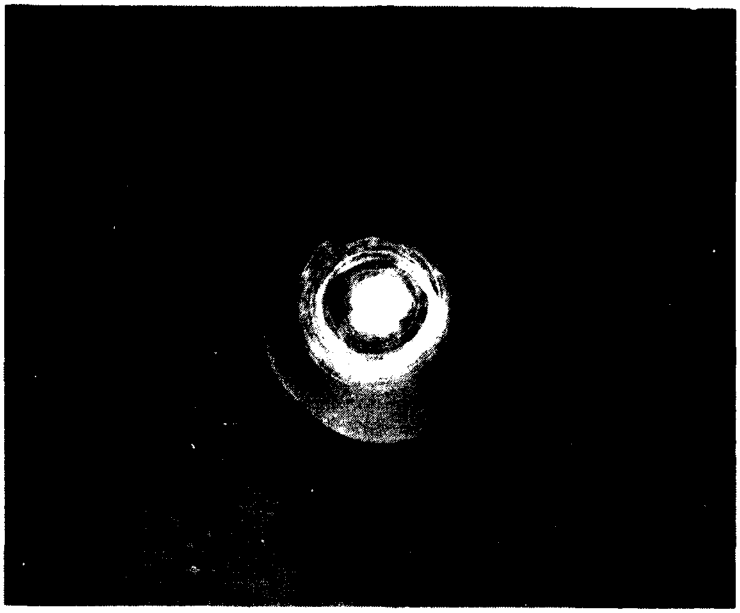

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Fig. 1 — Typical ball removed from a noisy bearing showing band of circular scratches x 1

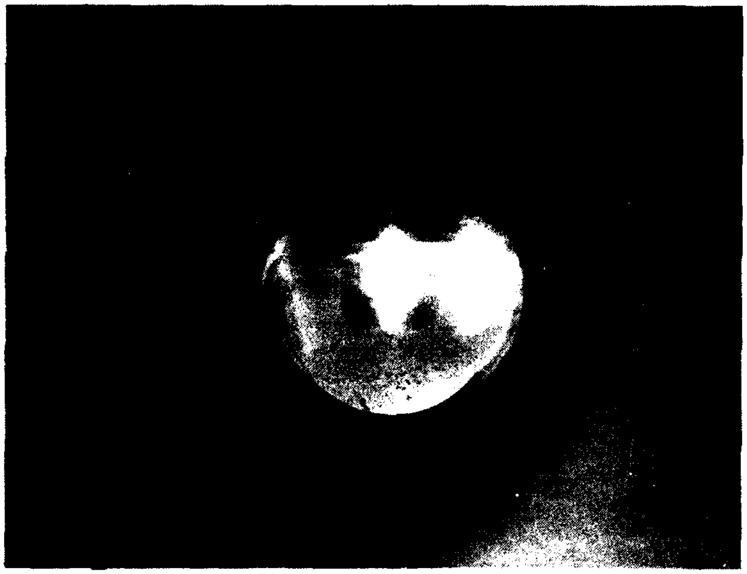

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Fig. 2a — Wide frost band found on surface of balls from quiet bearings x 1

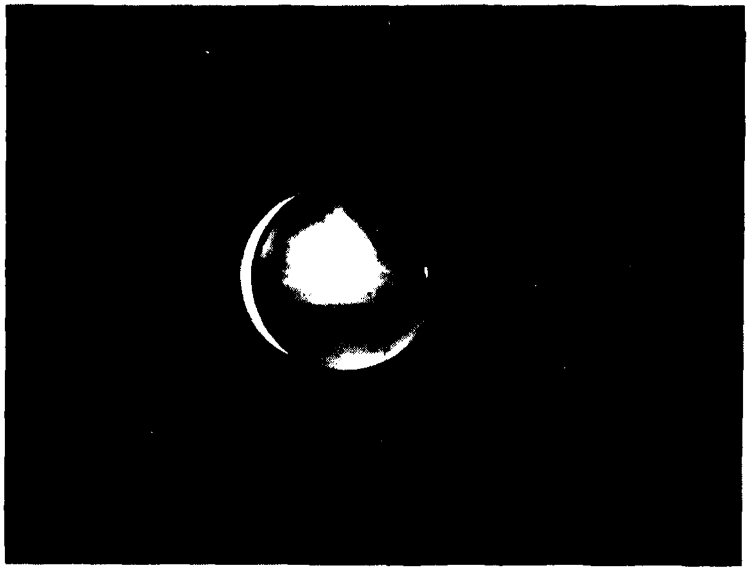

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Fig. 2b — Multiple frost bands occasionally found on surface of balls from quiet bearings x 1

Fig. 3 — SEM photograph of metal flake found in grease of bearing C-24 (quiet) x 20

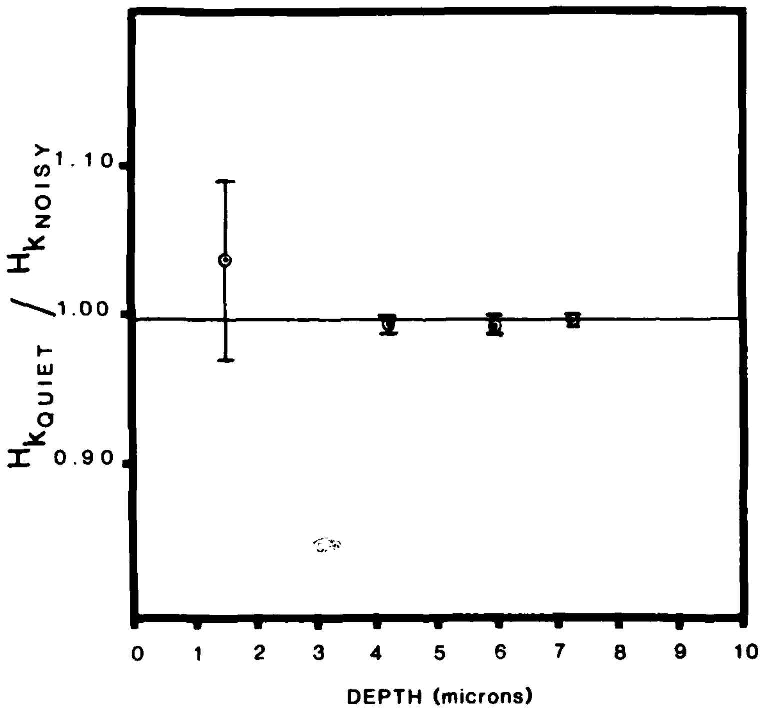

Fig. 4 — Comparative hardness of bearing balls

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